Steps in Risk Assessment:

2. Exposure Assessment:

    a. Site Conceptual Exposure Model

    Exposure Assessment includes development of a Site Conceptual Exposure Model (SCEM) which depicts all potential releases, exposure routes and actual and potential receptors who may be exposed via direct and indirect (cross-media transfer such as fate and transport via soil to groundwater and soil to air) exposure. All the contaminated media, viz. soil (entire soil column above the aquifer), groundwater, air, surface water, and sediment with COPC concentrations above screening levels will be included in the assessment. The quantitative risk assessment must consider both current and reasonably anticipated future land use scenarios. With regard to soil, it is preferred to evaluate residential (adult and child) exposure as the future land use scenario. If the facility wishes to assume a land use scenario other than residential, the facility should submit to DEQ an evaluation of potential future land use to provide a basis for the land use assumptions in the baseline risk assessment. See RCRA Corrective Action Fact Sheet #1 Land Use Assumptions for RCRA Corrective Action Baseline Risk Assessments at http://deq.state.va.us/Portals/0/DEQ/Land/lua2010.pdf for guidance on using a non-residential land use assumption in the risk assessment. Exposure routes for both the residential and industrial use scenarios will include ingestion, dermal absorption, and inhalation of vapors and dust particles.

    Fate and transport evaluation will be required to assess whether the contaminants remaining in soils will leach into groundwater at unacceptable levels. See RCRA Corrective Action Fact Sheet #2 Fate and Transport Modeling for RCRA Corrective Action Risk Assessments (http://deq.state.va.us/Portals/0/DEQ/Land/ftm2010.pdf) for guidance on evaluating fate and transport for soils.

    For groundwater (when included in quantitative risk assessment), residential (adult and child) exposure will be evaluated regardless of the selected land use scenario. Virginia considers all groundwater as potential source of drinking water therefore the risk assessment for industrial use assumption does not apply to the evaluation of groundwater. The groundwater exposure routes to be evaluated include ingestion, dermal absorption, and inhalation of volatiles emitted from the contaminated groundwater. Inhalation of vapors during showering and the potential for vapor intrusion of volatile contaminants to indoor air will be based on case-by-case basis depending on land use options, groundwater conditions, and/or institutional controls that will remain applicable to the site in future. Also see OSWER Technical Guide For Assessing And Mitigating The Vapor Intrusion Pathway From Subsurface Vapor Sources To Indoor Air for guidance on evaluating this pathway. Additional receptors may be evaluated based on site specific conditions, e.g., recreational user, fishing, etc. In some cases, if a facility

has agreed to an active cleanup to MCLs and risk-based screening levels, a risk assessment for the drinking water pathway may not be required. This decision should be made in consultation with the DEQ project manager and risk assessor.

Additional exposure pathways may include transfer of contaminated groundwater to surface water or sediment. Fate and transport evaluations will be required in those cases to assess whether the contaminants remaining in groundwater will leach into surface water or sediment at unacceptable levels. Porewater and sediment sampling results will be used to support/confirm modeling results and/or to calibrate the model.

b. Exposure Point Concentrations

Exposure Point Concentration (EPC) is an estimate of the concentration of a chemical in a medium at an exposure point. An exposure point (also called an exposure area or exposure unit) is a location within which an exposed receptor may reasonably be assumed to move at random and where contact with an environmental medium (e.g., soil) is equally likely at all sub-locations.

Reasonable maximum estimates (RME) of exposure concentrations will be developed for current and future land-use assumptions. RMEs can be developed for each unit individually or for a group of units or for the entire site. Any proposed groupings should be presented to the Department for approval prior to the quantitative risk assessment. The data set used in the risk assessment should be presented as follows: Sample ID, sample location, depth of sample, area the sample represents, COPC analyzed, MDL, maximum concentration detected and the 95% UCL. For statistical analysis, DEQ recommends the use of ProUCL software however, based on the data distribution the facility may use other statistical software. If software other than ProUCL is used, the facility must submit detailed information regarding the statistical evaluation performed (including the treatment of non-detects) for DEQ review. Please contact DEQ statistician Mr. Hasan Keceli (hasan.keceli@deq.virginia.gov) for further assistance. Regardless of the software used, the facility should submit both the inputs and outputs of the calculations to streamline the review. The facility will also provide a map identifying sampling locations that were used to derive the 95% UCL.

For evaluating cross-media transfer (i.e., from soil to air or soil to groundwater or groundwater to air) or off-site migration, modeling may be used to calculate exposure concentration. Some examples of models that may be used are:

Soil to air particulates: Soil Screening Guidance (EPA 1999c)
Soil to air volatiles: Soil Screening Guidance (EPA 1999c)
Groundwater to shower air: Foster and Chrostowski (2003)
Groundwater to outdoor air: ASTM E2081 - 00(2015) Standard Guide for Risk-Based Corrective Action (Previous standard ASTM PS104-98)

Soil to groundwater: SESOIL (Hetrick et al. 1989, Hetrick 1993)-SESOIL is included in REAMS software. Please contact Sonal Iyer (sonal.iyer@deq.virginia.gov) at DEQ for more information about REAMS. Note: While the overall approach and assumptions provided in DEQ's risk based closure guidance and REAMS manual remain valid and applicable, VURAM replaces and supersedes the risk assessment module of the REAMS software but does NOT replace the fate and transport modules of REAMS. Thus going forward, REAMS software must not be used for quantitative risk assessment. VURAM does not include fate and transport based modeling for soil-to-groundwater transfer, for which the facility may choose to use the SESOIL module of REAMS. Please contact DEQ for more details on fate and transport modeling.

When these models are used, the input and output parameters must be provided for DEQ evaluation.

c. Determining Chemical Intakes and Exposure Concentrations

In order to quantify human exposure to chemicals in the environment, it is necessary to calculate the level of contact between people and each contaminated environmental medium.

Chemical intake is the exposure to estimated amount of a constituent (i.e., EPC discussed above) normalized for time and body weight and is expressed in units of mg chemical/kg body weight-day.

Exposure concentration is the concentration of a chemical in transport or carrier medium (i.e., an environmental medium or contaminated food) at the point of contact and this term in RCRA Risk Assessment is used in relation to inhalation exposures. Exposure concentrations are typically expressed in units of $\mu g/m^3$ or mg/m^3.

For soils, chemical intakes should be calculated for ingestion, dermal contact, and inhalation (particulate and vapors) routes of exposure.

For groundwater (when included in quantitative risk assessment), chemical intakes should be calculated for ingestion, dermal contact, and inhalation (volatiles only) routes of exposure.

For air, exposure concentration for inhalation of volatile chemicals should be calculated.

Additional chemical intakes (e.g., surface water, food, sediment, recreation, trespasser) may be calculated based on site specific requirements.

EPA has identified several carcinogenic chemicals that act specifically via mutagenic mode of action. For maintaining consistency with EPA methodology, appropriate adjustments to accommodate for the mutagenic mode of action must be made while calculating chemical intakes and assessment of risk.

For carcinogens that act via a mutagenic mode of action, special adjustments are needed to account for susceptibility during early life. Therefore exposure to these chemicals must be assessed separately for ages 0-2, 2-6, 6-16, and 16-26 years by applying Age-Dependent Adjustment Factors (ADAFs). These are:

Age	ADAF
0-2	10
2-6	3
6-16	3
16 and up	1

Two receptor populations are typically evaluated: Residential and Industrial (indoor/outdoor) worker. The residential scenario is based on total exposure duration of 30 years. The default assumption is 6 years of childhood exposure and 20 years of adult exposure. Industrial worker scenario is based on a total duration of 25 years and includes only adult exposure. In Virginia all ground water is considered potential source of drinking water therefore only residential exposure scenario will be considered.

Some of the calculation algorithms to estimate chemical intake and exposure concentrations are provided below. For more details please refer to "User's Guide" on EPA Region 3 RSL website. The exposure defaults and calculations provided on EPA RSL website supersede the information provided below.

Exposure Route (oral and dermal)	**Chemical Intake (mg/kg-day)**	
	Residential Exposure	**Occupational/Industrial Exposure**
Ground Water		
Ingestion	$\frac{CW \times IRW_{adj} \times EF}{AT_c}$	$\frac{CW \times IRW_a \times EF_o \times ED}{BW_a \times AT}$
Dermal	$\frac{DAevent \times EV \times SA \times EF \times ED}{BW \times AT}$ $DAevent = Kp \times CW \times ET$ *DAevent for organic chemicals:* *If ET is less than t*:* $DA = 2 \times FA \times PC \times CW \times SQRT((6 \times tau \times ET)/pi)$	$\frac{DAevent \times EV \times SA \times EF \times ED}{BW \times AT}$ $DAevent = Kp \times CW \times ET$ *DAevent for organic chemicals:* *If ET is less than t*:* $DA = 2 \times FA \times Kp \times CW \times SQRT((6 \times tau \times ET)/pi)$

Exposure Route (oral and dermal)	**Chemical Intake (mg/kg-day)**	
	Residential Exposure	**Occupational/Industrial Exposure**
	If ET is greater than or equal to t:* $DA = FA \times PC \times CW \times \{(ET/(1+B)) + (2 \times tau \times [(1 + 3B+3 \times B2)/(1 + B)2]\}$	*If ET is greater than or equal to t*:* $DA = FA \times Kp \times CW \times \{(ET/(1+B)) + (2 \times tau \times [(1 + 3B+3 \times B2)/(1 + B)2]\}$
Soil		
Ingestion	$\frac{CS \times IRS_{adj} \times CF \times FI \times EF}{AT_c}$	$\frac{CS \times IR \times CF \times FI \times EF \times ED}{BW_a \times AT}$
Dermal	$\frac{CS \times CF \times SAS_{adj} \times AF \times ABS \times EF}{AT_c}$	$\frac{CS \times CF \times SAS_a \times AF \times ABS \times EF \times ED}{BW_a \times AT}$

Exposure Route (inhalation)	**Exposure Concentration (mg/m^3)**	
	Residential Exposure	**Occupational/Industrial Exposure**
Ground Water		
Inhalation	$\frac{CW \times EF \times ED \times K \times (ET/24\ hours/d)}{AT_c}$	$\frac{CW \times EF \times ED \times K \times (ET/24\ hours/d)}{AT}$
Soil		
Inhalation of vaporizing VOCs from soil	$\frac{CS \times 1/VF \times ED \times EF \times (ET/24\ hours/d)}{AT_c}$	$\frac{CS \times 1/VF \times ED \times EF \times (ET/24\ hours/d)}{AT}$
Inhalation of emitting particles from soil	$\frac{CS \times 1/PEF \times ED \times EF \times (ET/24\ hours/d)}{AT_c}$	$\frac{CS \times 1/PEF \times ED \times EF \times (ET/24\ hours/d)}{AT}$

The recommended default exposure parameters for calculating intake concentrations for residents and workers are provided in the following Table titled "Exposure defaults Included in Intake Calculations."

Exposure defaults Included in Intake Calculations			
Symbol	Term	Unit	Value
ABS	Absorption factor	-	User specified

Exposure defaults Included in Intake Calculations			
Symbol	Term	Unit	Value
AF	Adherence factor- Adult Adherence factor- Child	mg/cm^2	0.07 0.2
ATc	Averaging time carcinogens	days	25550
ATn	Averaging time non-carcinogens	days	ED x 365
B	lipophilic property	unitless	User specified
BWa	Body weight adult	kg	70
BWc	Body weight child	kg	15
CF	Conversion factor	-	0.000001
CS	Chemical concentration in soil	mg/Kg	User specified
CW	Chemical concentration in water	mg/L	User specified
EDC	Exposure duration child	years	6
EDtotal ED	Exposure duration for carcinogen total or Residential	years	30
EDO	Exposure duration occupational	years	25
EF	Exposure frequency Residential Occupational	days/year	350 250
ET	Exposure Time General/Occupational Groundwater Surface Water - ingestion Surface water - dermal Air -inhalation	hrs/day	 8.0 0.2 2.6 2.6 24.0
FI	Fraction ingested Residential Occupational	-	 1.0 1.0
FA	Fraction absorbed	-	1.0
IRAa	Inhalation rate air adult	m^3/day	20

Exposure defaults Included in Intake Calculations			
Symbol	Term	Unit	Value
IRAadj	Inhalation rate - air adjusted	mg/cm^2	11.66
IRAc	Inhalation rate child	m^3/day	12
IR	Ingestion rate food Fruit/veggies Fish	kg/day	0.28 0.122 0.054*
IRSa	Ingestion rate soil adult	mg/day	100
IRSc	Ingestion rate soil child	mg/day	200
IRSadj	Ingestion - soil adjusted	-	114.29
IRSC	Ingestion rate soil child	mg/day	200
IRWa	Ingestion rate water adult	L/day	2
IRWadj	Ingestion -water adjusted	L-y/kg-d	1.09
IRWc	Ingestion rate water child	L/day	1
K	Volatilization factor, water to air	L/m^3	0.5
PC	Permeability constant	cm/hr	User specified
PEF	Particulate emission factor	m^3/ kg	1.36E09
pi	-	-	3.14
SASa SASc	Surface area soil Residential - adult Child Industrial adult	cm^2/d	5700 2800 3300
SASadj	Surface area soil adjusted	Year-cm^2/kg-d	2290
t*	Time to reach steady state	hours	User specified
Tau	lag time	hours/event	User specified
VF	Volatilization factor, soil to air	m^3/kg	User specified

* : Subsistence rates may be higher